FUZZY LOGIC: IT'S COMPREHENSIBLE, IT'S PRACTICAL—AND IT'S COMMERCIAL

It simplifies tough problems and boosts the peformance of real-time control systems

by Larry Waller

Proponents of fuzzy-logic technology concede they have problems getting people to listen. The term "fuzzy," pinned on the group of concepts when they were developed back in 1965, proved too colorful a moniker to shake. The trouble is, putting "fuzzy" and "logic" together creates a mental conflict, which is especially acute for potential users who cut their programming teeth on classical Boolean logic's clear-cut precision.

Despite the semantic hurdle, however, fuzzy logic shows all the signs of breaking out of the near-cult status it has gained since its sudden appearance as an esoteric mathematical concept. Although developed at a U. S. university, practical fuzzy-logic applications are being spearheaded by the Japanese. With fuzzy logic used for real-time control of a Japanese subway system, it's clear that the technology is not a blue-sky dream: it can be both practical and reliable. It offers major advantages in real-world commercial applications, particularly in expert systems, where it makes tough problems much simpler to solve and radically improves system performance.

The Japanese are developing fuzzy logic with a will, both at the software level and in chips designed to execute fuzzy-logic algorithms. At the same time, a U. S. startup has developed a fuzzy-logic microprocessor for a body of customers who, again, are almost all Japanese.

The appeal of this form of logic stems from its ability to provide a straightforward, systematic framework for using approximate reasoning to solve complex programming problems. This form of reasoning enables programmers to deal easily with the kinds of imprecise quantifiers—like most, many, few, nearly zero, infrequently, about 100, and so on—that typically abound in human thinking about real-world situations. The fuzzy-logic approach gives the programmer a simple, graphic way to represent the meaning of these linguistic terms that is both mathematically rigorous and makes "tuning" the representation of those terms an integral part of the debugging process.

Fuzzy logic wraps up in a single system the standard-logic approach and probability theory, so a system takes into account different levels of uncertainty in, for example, expert-system production-rule evaluations. For practical work, it offers an entree to artificial intelligence developments—in contrast to the recognized complexity and disappointing results of conventional approaches in AI.

In Japan, fuzzy-logic hardware and software for industrial-control jobs are up and running in myriad tasks. Some 60 companies there, including the biggest names in industry, are reaping the first results of having plowed substantial research and development resources into the field during this decade.

By any standard, Japanese involvement can be described as mushrooming, says Lotfi A. Zadeh, who conceived the principles of fuzzy logic nearly a quarter century ago. A professor of electrical engineering and computer sciences at the University of California at Berkeley, his subsequent development of fuzzy logic, along with encouragement and consultation through the years, has earned him guru status among researchers.

> Most of the action is in Japan, but a U. S. startup now has a fuzzy-logic processor

The reason for the stepped-up pace is simple to fathom, he says, since the inherent nature of fuzzy logic so neatly fits the needs of this AI application. "Where human expertise is important [as in developing AI]," he says, "it is easier to express things in imprecise terms, the way people explain things verbally." Backers note that the less-complex programs are considerably smaller than equivalents done in conventional logic, up to an order of magnitude smaller in some cases.

FUZZY MOTORMAN. From its first use in 1980 in cement kilns in Sweden, one of the lowest-tech industrial-control tasks, fuzzy-logic hardware now has scored with one of the most demanding. A unit built by Hitachi Ltd., Tokyo, runs subway operations in Sendai, Japan, 200 miles north of Tokyo. It regulates train speed more precisely than the best human motorman and serves as a showcase for fuzzy-logic gear.

Similar hardware is going into elevator controls, and there are numerous units already controlling various automated production sequences across the industrial spectrum. Scarcely a month goes by without additional experimental hardware appearing. A system for parallel-parking automobiles without driver help, for example, impresses Zadeh because no other AI approach has been able to solve this tough problem.

Not quite all of the action centers in Japan: the U. S. startup Togai InfraLogic Inc. in Irvine, Calif., is the only firm founded just to capitalize on fuzzy logic. Since its formation last August, the company has designed a commercial processor and is implementing it in silicon for its largely Japanese client base. Togai has also introduced the first fuzzy compiler, for its proprietary Fuzzy-C language.

Masaki Togai, the firm's chief executive officer, has devoted his career to fuzzy logic since doing his doctoral work on the subject a decade ago at Duke University in Durham, N. C. Later, at AT&T Bell Laboratories in Murray Hill, N. J., he and fellow researcher Hiroyuki Watanabe designed and built the first experimental fuzzy-logic processing chip.

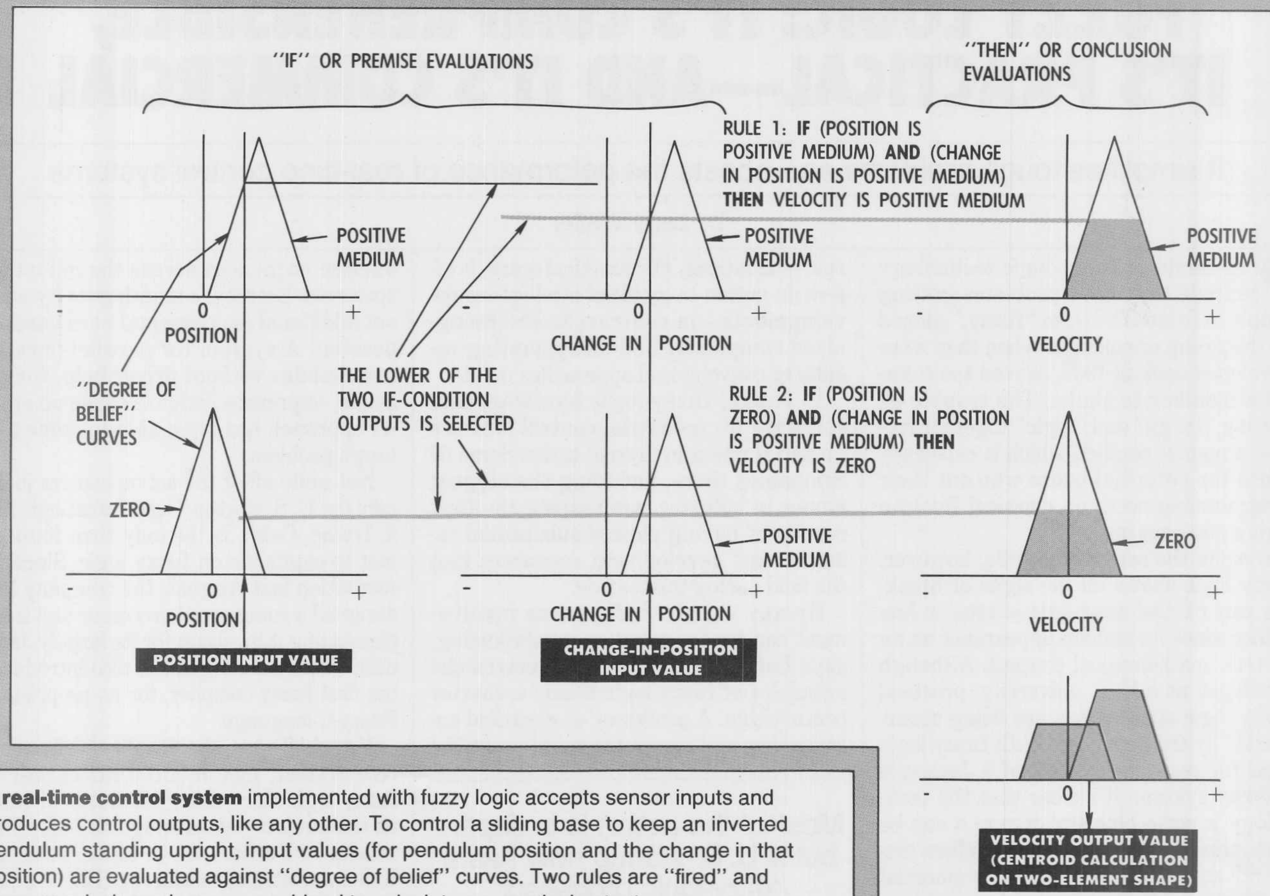
Togai InfraLogic is putting finishing touches on the final design of its microprocessor and will make samples available by summer for about $90 initially. The FC110 Digital Fuzzy Processor is intended as an embedded-system central-computing element. Optimized fuzzy-logic instructions give the chip the power to run the key inferencing operations some 20 times faster than an equivalent compiled program running on a 80386-based system, the company says.

In tests, a simulated FC110 running at 10 MHz executes about 28.6 thousand fuzzy-logic inferences per second (Kflips), compared with 2.3 Kflips for a 20-MHz 80386. The device resembles an 8-bit reduced-instruction-set computer architecturally, but its instruction set and addressing modes are designed for a fuzzy-knowledge base stored on a separate read-only memory and expressed in Fuzzy-C.

The Togai compiler supplies a graphics interface and tools for writing knowledge-based production rules. The programs can run on a general-purpose microcomputer, and soon on the FC110.

The plan from the beginning "was to have all the development tools ready be-

HOW FUZZY LOGIC DEALS WITH UNCERTAINTY



A real-time control system implemented with fuzzy logic accepts sensor inputs and produces control outputs, like any other. To control a sliding base to keep an inverted pendulum standing upright, input values (for pendulum position and the change in that position) are evaluated against "degree of belief" curves. Two rules are "fired" and fuzzy-conclusion values are combined to calculate a numerical output.

fore the chip," Togai says. But "we face a massive education task in teaching users an entirely new system." What makes it so different from conventional programming, of course, is that "there are no absolutes." The Togai compiler is the tool designed for developing expert systems that typically use a lot of imprecise information. Togai training material shows an experienced programmer how to describe in fuzzy-logic terms the "vague approximations embodied in [human] language," says Togai.

A BLACK ART. Handling the "membership functions" or "degree-of-belief curves," which are key descriptive elements that must be determined for any production rules in the knowledge base, for example, can be "somewhat of a black art," says Carl Perkins, vice president for business development at Togai. New terms must be learned, too, such as "defuzzification," which is a means offered by the compiler for generating a "crisp" data output—an actual numerical value—when needed. One way of defuzzifying is the centroid method, which produces the output by a center-of-gravity averaging technique. Another defuzzifies by picking an average of a centroid and other values.

The company has a training program on a floppy disk for personal computers. It illustrates fuzzy-logic principles through an example: controlling an inverted pendulum. The fuzzy controller uses sensor inputs for pendulum position and movement, evaluating those inputs with production rules to produce a control output for moving the base the pendulum stands on. By sliding the base back and forth, the controller balances the inverted pendulum, like a vertical rod balanced on the palm of a hand (see diagram).

The input values are evaluated as points on degree-of-belief curves. The curves have been arranged to approximate the meaning of linguistic expressions like "the position of the pendulum is zero." The expression indicates that the pendulum is at the zero-position angle, corresponding to the straight up, or balanced, position. Another expression, "the position is positive medium," means the pendulum is slightly to one side of the upright position.

Different points on one curve indicate the degree of belief, or the probability level, that the position is zero: belief is at its maximum exactly at zero, but belief tapers off gradually, rather than abruptly, as values diverge from the zero point. Simple triangular curves are often sufficient, says Perkins, but smoothing them out into bell-shaped curves can sometimes improve system accuracy.

Potential users may balk at the notion that some odd shape representing combinations of a very few "belief values" about where the pendulum is and how much it has moved can be used to perform this tricky real-time balancing act. But when they've gone through the demonstration, two things stand out: it's easy to set up, and it works very well as a solution to a complex problem.

Togai estimates that 10% of expert-system implementations will incorporate fuzzy logic in the near future. Consumer and business equipment have the most potential. "As soon as a fuzzy processor is built into an appliance or office-automation device, competing manufacturers will be forced to follow suit to maintain market share," he says. Some U. S. companies have projects looking at fuzzy logic, though at a pace well behind Japan.

The bedrock advantage comes from simplicity and the fact that when working with classical logic, "precision is expensive." One reason the Japanese lead the fuzzy-logic pack is that "they have found they don't need high accuracy in many applications and there's a significant payoff [from fuzzy logic]," Zadeh says. □